SPECIFICATION

DEMODULATION METHOD AND DEMODULATING APPARATUS

5   TECHNICAL FIELD

        The present invention relates to a
demodulating method and a demodulating apparatus
according to the trellis coded modulation in which
Turbo codes are used as element codes.

10

BACKGROUND ART

        Fig. 1 is a flowchart showing a
demodulating method according to the related art.
Referring to Fig. 1, in a processing block ST1, a
15   sequence $\{W'_k, V'_k\}$ of received signal
constellation points W'_k, V'_k (hereinafter,
referred to as received signal points) is received.
In ST2, soft-decision input values $w'_{1,k}$, $w'_{0,k}$,
$v'_{1,k}$, $v'_{0,k}$, provided as Turbo decoding inputs, and
20   low-order bit hard-decision values $h(w'_{1,k})$, $h(w'_{0,k})$,
$h(v'_{1,k})$, $h(v'_{0,k})$ are calculated based on the
sequence $\{W'_k, V'_k\}$ of the signal points. In ST3,
Turbo decoding is performed using the soft-decision
input values $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$, and the low-
25   order bit hard-decision values $h(w'_{1,k})$, $h(w'_{0,k})$,
$h(v'_{1,k})$, $h(v'_{0,k})$ so as to calculate the log-
likelihood ratio $L(u_k)$ of the low-order information
bit u_k. In ST4, an estimated value u'_k of a
transmitted low-order information bit is calculated
30   based on the log-likelihood ratio $L(u_k)$ of the low-

order information bit u_k. In ST5, hard-decision of a high-order information bit is performed based on the received signal points, so as to calculate estimated values $u'_{z,k}$, $u'_{z-1,k}$, ..., $u'_{3,k}$ of the

5   transmitted high-order information bit.

Fig. 2(a) shows an encoder used in the trellis coded modulation method that uses Turbo codes as element codes. Fig. 2(b) is an encoder used in 16QAM (quadrature amplitude modulation).

10   Fig. 2(c) shows a construction of a tone in a multi-carrier modulation and demodulation method. Referring to Fig. 2, a Turbo encoder 1 receives an input of two information bits and outputs two information bits and 2 redundancy bits. A

15   conversion 2 subjects a bit sequence output from the Turbo encoder to conversion. A mapper 3 converts the bit sequence converted by the conversion 2 into the signal points.

Fig. 3 shows a construction of the Turbo

20   encoder 1 of Fig. 2. Referring to Fig. 3, the Turbo encoder 1 includes a recursive systematic convolutional encoder 11, interleavers 12 and 13, a recursive systematic convolutional encoder 14 and a deinterleaver 15.

25   A description will now be given of the operation of the Turbo encoder 1.

The Turbo encoder 1 receives the sequence $u_{2,1}$, $u_{2,2}$, ..., $u_{2,k}$, ..., $u_{2,N}$ of low-order information bits (u_2 sequence) and the sequence $u_{1,1}$,

30   $u_{1,2}$, ..., $u_{1,k}$, ..., $u_{1,N}$ of the low-order information

bit (u_1 sequence) in the chronological order (time
1, 2, …, k, …, N).

That is, the recursive systematic
convolutional encoder 11 of the Turbo encoder 1
sequentially receives the u_2 sequence of low-order
information bits and the u_1 sequence of low-order
information bits for encoding and outputs a
sequence $u_{0a,1}$, $u_{0a,2}$, $u_{0a,3}$, …, $u_{0a,k}$, …, $u_{0a,N}$ of
parity bits (u_{0a} sequence).

The recursive systematic convolutional
encoder 14 of the Turbo encoder 1 sequentially
receives for encoding the u_2 sequence of low-order
information bits and the u_1 sequence of low-order
information bits interleaved by the interleaver 12
and outputs a sequence $u_{0b,1}$, $u_{0b,2}$, $u_{0b,3}$, …, $u_{0b,k}$, …,
$u_{0b,N}$ of parity bits (u_{0b} sequence).

The u_{0b} sequence of parity bits output
from the recursive systematic convolutional encoder
14 is synchronized by the deinterleaver 15 to the
original time.

The conversion 2 receives the u_1 low-
order bit sequence, the u_2 low-order bit sequence,
the u_{0a} parity-bit sequence and the u_{0b} parity-bit
sequence so as to perform the following operation
so that a receiver provides a uniform error
correction performance on transmitted data.

$$\begin{cases} w_{1,k} = u_{2,k} + u_{1,k} + u_{0a,k} + u_{0b,k} \\ w_{0,k} = u_{2,k} + u_{1,k} \\ v_{1,k} = u_{2,k} + u_{0a,k} \\ v_{0,k} = u_{2,k} \end{cases} \qquad (1)$$

Where w and v each corresponds to a tone shown in Fig. 2(c).

5   Fig. 4 shows constellations of signal points that occur in various digital modulation techniques. Fig. 4(a) shows a constellation of signal points in 4PSK (phase shift keying), Fig. 4(b) shows a constellation of signal points in 10 16QAM, and Fig. 4(c) shows a constellation of signal points in 64QAM. Referring to Fig. 4, symbols A, B, C and D denote cosets, which are determined after the conversion.

The low-order information bits u_1 and u_2 15 and the parity bits u_{0a} and u_{0b} are used to determine w_1, w_0, v_1, v_0. The coset is determined by (w_1, w_0) or (v_1, v_0), as shown in Fig. 4(d).

Designation of four mutually adjacent signal points to be transmitted is based on the 20 selection of coset.

When the coset is determined, the mapper 3 receives the coset and the high-order information bit so as to determine the transmitted signal point W or the transmitted signal point V based on the 25 constellation of Fig. 4.

On the receiving side, the received signal point W' or the received signal point V' is subject to hard-decision so as to estimate a sequence of most likely information bits

5   (transmitted data).

That is, the signal point with a minimum distance from the received signal point is determined to be transmitted data. For the received signal point W' or the received signal point V',

10 the four points closest to the received signal point constitute cosets A, B, C and D, respectively, in any of Figs. 4(a), 4(b) and 4(c).

The four signal points with minimum point-to-point distance are likely to suffer from

15 deterioration in the reception. Accordingly, in the related art, the low-order two bits for determination of the four immediately adjacent signal points are subject to the Turbo coding capable of excellent error correction. The decoder

20 performs soft-decision according to the Turbo decoding so as to estimate the transmitted low-order information bit.

In contrast, signal points other than the four immediately adjacent signal points suffer

25 a relatively serious deterioration in the reception. The high-order information bits for identification of these signal points (for example, the high-order information bit sequence u6, u5, u4, u3 of Fig. 2(c) are therefore subject to hard-decision by the

30 decoder so as to estimate transmitted high-order

information bit (i.e. determine (w_3, w_2), (v_3, v_2)).

A specific description will now be given of the demodulation method according to the related art.

5   In step ST1, the sequence $\{W'_k, V'_k\}$ of the received signal points W'_k, V'_k is received, where k indicates time maintained in the Turbo encoder.

In step ST2, the soft-decision values
10    $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$, provided as Turbo decoding inputs, and the low-order bit hard-decision values $h(w'_{1,k})$, $h(w'_{0,k})$, $h(v'_{1,k})$, $h(v'_{0,k})$ are calculated based on the sequence $\{W'_k, V'_k\}$ of the signal points. Hard-decision of the low-order bit is
15   performed by determining the coset closest to the received signal point. Referring, for example, to Fig. 8(b), the coset B is closest to the received signal point 26 so that the low-order bits resulting from hard-decision are $h(w'_{1,k})=0$,
20    $h(w'_{0,k})=1$ (Fig. 8(d)).

We focus on the transmitted signal point 25 and the received signal point 26 of Fig. 8(b). The transmitted signal point 25 is assumed to be located at (X,Y) in the X-Y coordinate of the W
25   signal state space and the received signal point 26 is assumed to be located at (X',Y') in the X-Y coordinate of the W' signal state space.

A square Euclidean distance 27 between the transmitted signal point 25 and the received
30   signal point 26 is calculated as follows.

$$d^2(W', \ W) = (X'-X)^2 + (Y'-Y)^2 \qquad\qquad (2)$$

In step ST3, Turbo decoding is performed using the soft-decision input values $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$, and the low-order bit hard-decision

5 values $h(w'_{1,k})$, $h(w'_{0,k})$, $h(v'_{1,k})$, $h(v'_{0,k})$ so as to calculate the log-likelihood ratio $L(u_k)$ of the low-order information bit u_k

In ST4, an estimated value u'_k of a transmitted low-order information bit is calculated

10 based on the log-likelihood ratio $L(u_k)$ of the low-order information bit u_k calculated in step ST3.

In ST5, hard-decision of the high-order information bit is performed based on the received signal point 26 so as to calculate estimated values

15 $u'_{z,k}$, $u'_{z-1,k}$, …, $u'_{3,k}$ of the transmitted high-order information bit.

With the above-described arrangement of the related-art demodulating method, the transmitted low-order information bit is accurately

20 estimated. However, since the transmitted high-order information bit is estimated by hard-decision based on the received signal point 26, the transmitted high-order information bit may incur improper error correction.

25 For example, assuming that, in response to a transmitted signal point 20, the signal point 21 is received as shown in Fig. 8(a). Since the hard-decision is performed in blocks defined by solid lines in Fig. 8(a), a high-order information

30 bit determination area 24 may be used as an area

for determination when a high-order information bit
determination area 23 should actually be used,
resulting in improper error correction of the
transmitted high-order information bit.

5   The present invention has been developed
in order to resolve the problems described above
and has an object of providing a demodulating
method and a demodulating apparatus in which the
high-order information bit is accurately estimated
10   so that the probability of error in decoding the
high-order information bit is reduced.

DISCLOSURE OF THE INVENTION

The aforementioned objects can be
15   achieved by a demodulation method comprising: a
log-likelihood ratio calculation step for
calculating soft-decision input values of Turbo
decoding upon receipt of a sequence of received
signal points, performing Turbo decoding using the
20   soft-decision input values, and calculating a log-
likelihood ratio of a low-order information bit and
a log-likelihood ratio of a parity bit; a coset
estimation step for estimating the low-order
information bit based on the log-likelihood ratio
25   of the low-order information bit calculated by the
log-likelihood ratio calculation step, estimating
the parity bit based on the log-likelihood ratio of
the parity bit calculated by the log-likelihood
ratio calculation step, so as to estimate a coset
30   based on the low-order information bit and the

parity bit; and high-order information bit estimation step for estimating a transmitted signal point based on the coset estimated by the coset estimation step, so as to estimate the high-order

5   information bit based on the transmitted signal point.

Accordingly, it is possible to estimate the high-order information bit accurately so that the probability of errors in decoding the high-

10   order information bit is reduced.

The log-likelihood ratio calculation step may calculate an Euclidean distance from a threshold value of a signal point constellation in a signal state space and use the calculated

15   distance as soft-decision input values of the Turbo decoding.

With this, the soft-decision input values of Turbo decoding can be obtained in a relatively simple manner.

20   The log-likelihood ratio calculation step may perform the Turbo decoding for calculating a branch metric of trellis using a linear sum of the soft-decision input values, so as to calculate the log-likelihood ratio of the low-order

25   information bit and the log-likelihood ratio of the parity bit.

With this, the process of calculation can be simplified.

The log-likelihood ratio calculation

30   step may perform the Turbo decoding that includes

conversion.

With this, the probability of errors in decoding the high-order information bit can be reduced when the conversion is included.

5   The log-likelihood ratio calculation step may calculate an Euclidean distance from a threshold value of a signal point constellation in a signal state space so as to use the calculated distance as the soft-decision input values of the

10   Turbo decoding that includes conversion, perform the Turbo decoding whereby a branch metric of trellis is calculated using a linear sum of the soft-decision input values, so as to calculate the log-likelihood ratio of the low-order information

15   bit and the log-likelihood ratio of the parity bit.

With this, the high-order information bit can be accurately estimated so that the probability of errors in decoding the high-order information bit is reduced.

20   The aforementioned objects can also be achieved by demodulation apparatus comprising: log-likelihood ratio calculation means for calculating soft-decision input values of Turbo decoding upon receipt of a sequence of received signal points,

25   performs Turbo decoding using the soft-decision input values, and calculating a log-likelihood ratio of a low-order information bit and a log-likelihood ratio of a parity bit; a coset estimation means for estimating the low-order

30   information bit based on the log-likelihood ratio

of the low-order information bit calculated by the log-likelihood ratio calculation means, estimating the parity bit based on the log-likelihood ratio of the parity bit calculated by the log-likelihood

5 ratio calculation means, so as to estimate a coset based on the low-order information bit and the parity bit; and high-order information bit estimation means for estimating a transmitted signal point based on the coset estimated by the

10 coset estimation means so as to estimate a high-order information bit based on the transmitted signal point.

The log-likelihood ratio calculation means may calculate an Euclidean distance from a

15 threshold value of a signal point constellation in a signal state space and use the calculated distance as soft-decision input values of the Turbo decoding.

With this, the soft-decision input

20 values of the Turbo decoding can be obtained in a relatively simple manner.

The log-likelihood ratio calculation means may perform the Turbo decoding for calculating a branch metric of trellis using a

25 linear sum of the soft-decision input values, so as to calculate the log-likelihood ratio of the low-order information bit and the log-likelihood ratio of the parity bit.

With this, the process of calculation

30 can be simplified.

The log-likelihood ratio calculation means may perform the Turbo decoding that includes conversion.

With this, the probability of errors in decoding the high-order information bit is reduced when the conversion is included.

The log-likelihood ratio calculation means may calculate an Euclidean distance from a threshold value of a signal point constellation in a signal state space so as to use the calculated distance as the soft-decision input values of the Turbo decoding that includes conversion, perform the Turbo decoding whereby a branch metric of trellis is calculated using a linear sum of the soft-decision input values, so as to calculate the log-likelihood ratio of the low-order information bit and the log-likelihood ratio of the parity bit.

With this, the probability of errors in decoding the high-order information bit is reduced when the conversion is included.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a flowchart showing a demodulating method according to the related art;

Fig. 2(a) shows an encoder used in the trellis coded modulation method that uses Turbo codes as element codes;

Fig. 2(b) is an encoder used in 16QAM;

Fig. 2(c) shows a construction of a tone in a multi-carrier modulation and demodulation

method;

Fig. 3 shows a construction of the Turbo encoder of Fig. 2;

Fig. 4 shows constellations of signal points that occur in various digital modulation techniques;

Fig. 5 is a flowchart showing a demodulating method according to a first embodiment of the present invention;

Fig. 6 is a graph showing the probability of decoding error when the decoding according to the invention is performed;

Fig. 7 shows a demodulating apparatus according to a second embodiment of the present invention; and

Fig. 8 shows areas for determination of high-order information bit and the like.

BEST MODE OF CARRYING OUT THE INVENTION

In the following, the best mode of carrying out the invention will be described with reference to the attached drawings.

First embodiment

Fig. 5 is a flowchart showing a demodulating method according to a first embodiment of the present invention. Referring to Fig. 5, a sequence $\{W'_k, V'_k\}$ of the received signal points W'_k, V'_k is received in step ST11. In ST12, soft-decision input values $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$, provided as Turbo decoding inputs, and low-order

bit hard-decision values $h(w'_{1,k})$, $h(w'_{0,k})$, $h(v'_{1,k})$, $h(v'_{0,k})$ are calculated based on the sequence $\{W'_k, V'_k\}$ of the signal points. In ST13, Turbo decoding is performed using the soft-decision input values

5    $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$, and the low-order bit hard-decision values $h(w'_{1,k})$, $h(w'_{0,k})$, $h(v'_{1,k})$, $h(v'_{0,k})$ so as to calculate the log-likelihood ratio $L(u_k)$ of the low-order information bit and the log-likelihood ratio $L(u_{0a,k})$, $L(u_{0b,k})$ of the parity

10   bit. The reception ST11 and the calculation steps ST12 and ST13 constitute a log-likelihood ratio calculation step.

In step ST14, an estimated value u'_k of the low-order information bit is calculated based

15   on the log-likelihood ratio $L(u_k)$ of the low-order information bit. In step ST15, estimated values $u'_{0a,k}$, $u'_{0b,k}$ of the parity bit are calculated based on the log-likelihood ratio $L(u_{0a,k})$, $L(u_{0b,k})$ of the parity bit. In ST16, an estimated value $u'_{coset,k}$ of

20   the coset is calculated based on the estimated value u'_k of the low-order information bit and the estimated values $u'_{0a,k}$, $u'_{0b,k}$ of the parity bit. The estimated value calculation steps ST14-ST16 constitute a coset estimation step.

25   In step ST17, estimated values W''_k, V''_k of the transmitted signal point are calculated based on the estimated value $u'_{coset,k}$ of the coset. In step ST18, estimated values $u'_{z,k}$, $u'_{z-1,k}$, …, $u'_{3,k}$ of the high-order information bit are

30   calculated based on the estimated values W''_k, V''_k

of the transmitted signal point. The estimated
value calculation steps ST17 and ST18 constitute a
high-order information bit estimation step.

A description will now be given of the
5 operation according to the first embodiment.

It is assumed that the transmitted
signal points W_k, V_k obtained as a result of multi-
value QAM are affected by noise. In step ST11, a
sequence $\{W'_k, V'_k\}$ of the received signal points
10 W'_k, V'_k is received, where k denotes time
maintained by the Turbo encoder.

In the subsequent step ST12, soft-
decision input values $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$,
provided as Turbo decoding inputs, and low-order
15 bit hard-decision values $h(w'_{1,k})$, $h(w'_{0,k})$, $h(v'_{1,k})$,
$h(v'_{0,k})$ are calculated based on the sequence $\{W'_k,
V'_k\}$ of the signal points.

$$\begin{cases} w'_{1,k} = d'_{0,X,k} \\ w'_{0,k} = d'_{0,Y,k} \\ v'_{1,k} = d'_{1,X,k} \\ v'_{0,k} = d'_{1,Y,k} \end{cases} \qquad (3)$$

20

where $d'_{0,x,k}$, $d'_{1,x,k}$ indicates a Euclidean distance
28 from a threshold value illustrated in Fig. 8(c),
and $d'_{0,Y,k}$, $d'_{1,Y,k}$ indicates a Euclidean distance 29
from a threshold value shown in Fig. 8(c).
25 Subsequently, in step ST13, Turbo
decoding is performed using the soft-decision input

values $W'_{1,k}$, $W'_{0,k}$, $V'_{1,k}$, $V'_{0,k}$, and the low-order
bit hard-decision values $h(W'_{1,k})$, $h(W'_{0,k})$, $h(V'_{1,k})$,
$h(V'_{0,k})$ so as to the calculate the log-likelihood
ratio $L(u_k)$ of the low-order information bit u_k.

5   The low-order information bit u_k indicates a pair
$(u_{2,k}, u_{1,k})$ input to the Turbo encoder of Fig. 3.

More specifically, the log-likelihood
ratio $L(u_k)$ of the low-order information bit is
calculated as follows.

10   Given, for example, that $u_{2,k}=0$, $u_{1,k}=0$
(hereinafter, simply represented as $u_k=00$) are
designated as reference information bits, the log-
likelihood ratio $L(u_k=00)$ for the transmitted
information bit of $u_k=00$ is calculated as follows

15   upon receipt of the sequence $\{W'_k, V'_k\}$ of the
received signal points W'_k, V'_k.

$$L(u_k = 00) = \ln \frac{\Pr(u_k = 00 \mid \{W'_k, V'_k\})}{\Pr(u_k = 00 \mid \{W'_k, V'_k\})} \qquad (4)$$

20   In this case, the log-likelihood $L(u_k=00)=0$ because
$u_k=00$ is used as reference information bit.

The likelihood $L(u_k=01)$ for the
transmitted information bit $u_k=01$, the likelihood
$L(u_k=10)$ for $u_k=10$, the likelihood $L(u_k=11)$ for

25    $u_k=11$, upon receipt of the sequence $\{W'_k, V'_k\}$ of
the received signal points W'_k, V'_k, are calculated
as follows.

$$L(u_k = 01) = \ln \frac{Pr(u_k = 01 \,|\, \{W'_k, V'_k\})}{Pr(u_k = 00 \,|\, \{W'_k, V'_k\})} \qquad (5)$$

$$L(u_k = 10) = \ln \frac{Pr(u_k = 10 \,|\, \{W'_k, V'_k\})}{Pr(u_k = 00 \,|\, \{W'_k, V'_k\})} \qquad (6)$$

$$L(u_k = 11) = \ln \frac{Pr(u_k = 11 \,|\, \{W'_k, V'_k\})}{Pr(u_k = 00 \,|\, \{W'_k, V'_k\})} \qquad (7)$$

where $Pr(u_k=00\,|\,\{W'_k, V'_k\})$ indicates conditional

5   probability for the transmitted information bit of
$u_{2,k}=0$, $u_{1,k}=0$ when the sequence $\{W'_k, V'_k\}$ of the
received signal points W'_k, V'_k is received.

Similarly, $Pr(u_k=01\,|\,\{W'_k, V'_k\})$ indicates
conditional probability for the transmitted

10   information bit of $u_{2,k}=0$, $u_{1,k}=1$ when the sequence
$\{W'_k, V'_k\}$ of the received signal points W'_k, V'_k is
received; $Pr(u_k=10\,|\,\{W'_k, V'_k\})$ indicates conditional
probability for the transmitted information bit of
$u_{2,k}=1$, $u_{1,k}=0$ when the sequence $\{W'_k, V'_k\}$ of the

15   received signal points W'_k, V'_k is received; and
$Pr(u_k=11\,|\,\{W'_k, V'_k\})$ indicates conditional
probability for the transmitted information bit of
$u_{2,k}=1$, $u_{1,k}=1$ when the sequence $\{W'_k, V'_k\}$ of the
received signal points W'_k, V'_k is received.

20   In step ST13, the log-likelihood $L(u_{0a,k})$,
$L(u_{0b,k})$ of the parity bit is also calculated. Not
only that the low-order information bit is subject
to Turbo encoding but also that the parity bit

generated as a result of Turbo encoding is included in the transmitted signal points.

More specifically, the log-likelihood ratio $L(u_{0a,k})$ for the parity bit $u_{0a,k}$ output from the recursive systematic convolutional encoder 11 of the Turbo encoder 1 and the log-likelihood ratio $L(u_{0b,k})$ for the parity bit $u_{0b,k}$ output from the recursive systematic convolutional encoder 14 are calculated as follows.

$$L(u_{0a,k}) = \ln \frac{Pr(u_{0a,k} = 1 | \{W'_k, V'_k\})}{Pr(u_{0a,k} = 0 | \{W'_k, V'_k\})} \qquad (8)$$

$$L(u_{0b,k}) = \ln \frac{Pr(u_{0b,k} = 1 | \{W'_k, V'_k\})}{Pr(u_{0b,k} = 0 | \{W'_k, V'_k\})} \qquad (9)$$

where $Pr(u_{0a,k}=0 | \{W'_k, V'_k\})$ indicates conditional probability for the parity bit of $u_{0a,k}=0$ when the sequence $\{W'_k, V'_k\}$ of the received signal points W'_k, V'_k is received; and $Pr(u_{0a,k}=1 | \{W'_k, V'_k\})$ indicates conditional probability for the parity bit of $u_{0a,k}=1$ when the sequence $\{W'_k, V'_k\}$ of the received signal points W'_k, V'_k is received

Similarly, $Pr(u_{0b,k}=0 | \{W'_k, V'_k\})$ indicates conditional probability for the parity bit of $u_{0b,k}=0$ when the sequence $\{W'_k, V'_k\}$ of the received signal points W'_k, V'_k is received; and $Pr(u_{0b,k}=1 | \{W'_k, V'_k\})$ indicates conditional

probability for the parity bit of $u_{0b,k}=1$ when the sequence $\{W'_k, V'_k\}$ of the received signal points W'_k, V'_k is received

In step ST14, an estimated value u'_k of the low-order information bit u_k is calculated based on the log-likelihood ratios $L(u_k=00)$, $L(u_k=01)$, $L(u_k=10)$, $L(u_k=11)$ of the low-order information bit.

More specifically, the information bit that corresponds to one of the log-likelihood ratios $L(u_k=00)$, $L(u_k=01)$, $L(u_k=10)$, $L(u_k=11)$, of the low-order information bit, that assumes the maximum value is designated as the estimated value u'_k of the low-order information bit.

Step ST15 is performed concurrently with step ST14 so that the estimated values $u'_{0a,k}$, $u'_{0b,k}$ of the parity bit are calculated based on the log-likelihood ratio $L(u_{0a,k})$, $L(u_{0b,k})$ of the parity bit.

More specifically, when it is determined that the log-likelihood ratio $L(u_{0a,k})>0$, the parity bit estimated value $u'_{0a,k}$ is determined to be "1". When $L(u_{0a,k})\leq0$, the parity bit estimated value $u'_{0a,k}$ is determined to be "0".

Subsequently, in step ST16, an estimated value $u'_{coset,k}$ of the coset is calculated based on the estimated value u'_k of the low-order information bit and the estimated values $u'_{0a,k}$, $u'_{0b,k}$ of the parity bit.

For example, when the conversion 2 of Figs. 2(a) and 2(b) provides the performance of

equation (1), the following steps are performed so as to calculate $w''_{1,k}$, $w''_{0,k}$, $v''_{1,k}$, $v''_{0,k}$.

$$\begin{cases} w''_{1,k} = u'_{2,k} + u'_{1,k} + u'_{0a,k} + u'_{0b,k} \\ w''_{0,k} = u'_{2,k} + u'_{1,k} \\ v''_{1,k} = u'_{2,k} + u'_{0a,k} \\ v''_{0,k} = u'_{2,k} \end{cases} \qquad (10)$$

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The table of Fig. 4(d) is referred to so as to determine the estimated value $u'_{coset,k}$ of the coset.

In step ST17, estimated values W''_k, V''_k of the transmitted signal point are calculated

10　based on the estimated value $u'_{coset,k}$ of the coset. The estimated values $u'_{coset,k}$ of the coset closest to the received signal points W'_k, V'_k are designated as estimated values W''_k, V''_k of the transmitted signal points.

15　Finally, in step ST18, estimated values $u'_{z,k}$, $u'_{z-1,k}$, ..., $u'_{3,k}$ of the high-order information bit are calculated based on the estimated values W''_k, V''_k of the transmitted signal points.

As has been described, the first

20　embodiment includes a coset estimation step for estimating the low-order information bit based on the log-likelihood of the low-order information bit and estimating the parity bit based on the log-likelihood ratio of the parity bit, so as to

25　estimate the coset based on the low-order information bit and the parity bit. The first

embodiment further includes a high-order information bit estimation step for estimating transmitted signal points based on the coset and estimating the high-order information bit based on

5   the transmitted signal points. With this, the high-order information bit is accurately estimated so that the probability of error in decoding the high-order information bit is reduced.

One thing to be noted is that the volume

10   of calculation is increased as a result of implementing the first embodiment. Extra steps for calculation required at the last stage of recursive decoding are the calculation of the log-likelihood ratio of the parity bit $L(u_{0a,k})$, $L(u_{0b,k})$ of the

15   parity bit, calculation of the estimated values $u'_{0a,k}$, $u'_{0a,k}$ of the transmitted parity bit, and calculation of the estimated value $u'_{coset,k}$ of the transmitted coset. However, these steps of calculation are performed at the last cycle of

20   recursion requiring only a small increase in the volume of calculation.

Fig. 6 is a graph showing decoding error probability occurring when the demodulation method of the first embodiment and that of the related art

25   are performed. In Fig. 6, a ratio (E_b/N_0) between transmission power and noise power per information bit is plotted horizontally, and a bit error probability of the high-order information bit is plotted vertically.

30   The demodulation method according to the

related art and that of the first embodiment are the same in that both provide same level of decoding error probability of the low-order information bit. However, as obviously shown in Fig.

5   6, the demodulating method according to the first embodiment is superior in that the decoding error probability of the high-order information bit is significantly reduced as compared to the related art.

10   The decoding error probability of the high-order information bit is significantly reduced for the following reasons.

It is assumed that the signal point 20 (Fig. 8(a)) is transmitted, the signal point 21 is

15 received and the low-order information bit is accurately estimated as a result of Turbo encoding. As already described, according to the related art, hard decision is performed in areas indicated by solid lines in Fig. 8(a). Therefore, the area 24

20 may be erroneously selected for determination of the high-order information bit, when actually the area 23 should be selected instead of the are 24, resulting in a correction error.

In contrast, according to the first

25 embodiment, one of the points constituting a coset C which point is closest to the received signal point is determined to be the transmitted signal point. By determining that the point constituting the coset C which point is closest to the received

30 signal point is the transmitted signal point 20,

transmitted signal point 20 can be accurately recovered. Since the area 23 can properly be selected for determination of the high-order information bit, the high-order information bit can

5 be accurately determined. Where the related-art may produce a correction error, the method according to the first embodiment could provide an accurate correction. Accordingly, the decoding error probability of the high-order information bit is

10 successfully reduced.

Second embodiment

Fig. 7 shows a construction of a demodulating apparatus according to a second

15 embodiment of the present invention. Referring to Fig. 7, the demodulating apparatus comprises a log-likelihood ratio calculation means 30, a soft-decision input value calculator 31 for calculating soft-decision input values $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$,

20 provided as Turbo decoding inputs, and low-order bit hard-decision values $h(w'_{1,k})$, $h(w'_{0,k})$, $h(v'_{1,k})$, $h(v'_{0,k})$, based on the sequence $\{W'_k, V'_k\}$ of the signal points W'_k, V'_k. The demodulating apparatus further comprises a decoder 32 whereby Turbo

25 decoding is performed using the soft-decision input values $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$, and the low-order bit hard-decision values $h(w'_{1,k})$, $h(w'_{0,k})$, $h(v'_{1,k})$, $h(v'_{0,k})$ so as to calculate the log-likelihood ratio $L(u_k)$ of the low-order information bit and the log-

30 likelihood ratio $L(u_{0a,k})$ of the parity bit.

Numeral 33 indicates a received amplitude calculator for calculating a received amplitude value $L_{ch}(u_k)$, based on the soft-decision input values $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$, and the low-

5 order bit hard-decision values $h(w'_{1,k})$, $h(w'_{0,k})$, $h(v'_{1,k})$, $h(v'_{0,k})$. Numeral 34 indicates a subtractor for subtracting the received amplitude value $L_{ch}(u_k)$ and a priori probability ratio $L_a(u_k)$ from the log-likelihood ratio $L(u_k)$ of the low-order information

10 bit so as to output an extrinsic information probability ratio $L_e(u_k)$. Numeral 35 indicates an interleaver for interleaving the extrinsic information probability ratio $L_e(u_k)$ for synchronization with the recursive systematic

15 convolutional encoder 14 and outputs a result of interleaving as a priori probability ratio $L_a(u_k)$. Numeral 36 indicates an interleaver for interleaving the soft-decision input values $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$, and the low-order bit hard-

20 decision values $h(w'_{1,k})$, $h(w'_{0,k})$, $h(v'_{1,k})$, $h(v'_{0,k})$ for synchronization with the recursive systematic convolutional encoder 14. Numeral 37 indicates an interleaver for interleaving the received amplitude value $L_{ch}(u_k)$ for synchronization with the recursive

25 systematic convolutional encoder 14.

Numeral 38 indicates a decoder whereby Turbo decoding is performed using the soft-decision input values $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$, and the low-order bit hard-decision values $h(w'_{1,k})$, $h(w'_{0,k})$,

30 $h(v'_{1,k})$, $h(v'_{0,k})$ so as to calculate the log-

likelihood ratio $L(u_k)$ of the low-order information bit and the log-likelihood ratio $L(u_{0b,k})$ of the parity bit generated by the recursive systematic convolutional encoder 14. Numeral 39 indicates a

5 subtractor for subtracting the received amplitude value $L_{ch}(u_k)$ and a priori probability ratio $L_a(u_k)$ from the log-likelihood ratio $L(u_k)$ of the low-order information bit so as to output an extrinsic information probability ratio $L_e(u_k)$. Numeral 40

10 indicates an interleaver for interleaving the extrinsic information $L_e(u_k)$ for synchronization with the recursive systematic convolutional encoder 11 so as to output a result of interleaving as a priori probability ratio $L_a(u_k)$. Numeral 41

15 indicates a switch initially connected to side I and connected to side II at second and subsequent cycles for decoding.

Numeral 42 indicates a coset estimation means. Numeral 43 indicates a determination unit

20 for determining the parity bit of the recursive systematic convolutional encoder 11, based on the log-likelihood ratio $L(u_{0a,k})$ of the parity bit calculated by the decoder 32 so as to calculate an estimated value $u'_{0a,k}$ of the original transmitted

25 parity. Numeral 44 indicates a determination unit for determining the low-order information bit and the parity bit of the recursive systematic convolutional encoder 14, based on the log-likelihood ratio $L(u_k)$ of the low-order information bit and the log-likelihood ratio $L(u_{0a,k})$ of the

30 bit and the log-likelihood ratio $L(u_{0a,k})$ of the

parity bit calculated by the decoder 38 so as to calculate an estimated value $u'_k (=u'_{2,k}, u'_{1,k})$ of the original transmitted low-order information bit and an estimated value $u'_{0b,k}$ of the original

5   transmitted parity. Numeral 45 indicates a determination unit for calculating an estimated value $u'_{coset,k}$ of the coset, based on the estimated value $u'_k (=u'_{2,k}, u'_{1,k})$ of the original transmitted low-order information bit and the estimated values

10    $u'_{0a,k}$ and $u'_{0b,k}$ of the original transmitted parity. Numeral 46 indicates a determination unit (high-order bit estimation means) for calculating estimated values $u'_{z,k}, u'_{z-1,k}, …, u'_{3,k}$ of the high-order information bit, based on the received signal

15   points W'_k and V'_k and the estimated value $u'_{coset,k}$ of the coset.

     A description will now be given of the operation according to the second embodiment.

     The soft-decision input value calculator

20   31 receives the sequence $\{W'_k, V'_k\}$ of the signal points W'_k, V'_k and determines the soft-decision input values $w'_{1,k}, w'_{0,k}, v'_{1,k}, v'_{0,k}$, provided as Turbo decoding inputs, and low-order bit hard-decision values $h(w'_{1,k}), h(w'_{0,k}), h(v'_{1,k}), h(v'_{0,k})$,

25   by performing the calculation of equation (3).

     When the soft-decision input value calculator 31 calculates the soft-decision input values $w'_{1,k}, w'_{0,k}, v'_{1,k}, v'_{0,k}$, provided as Turbo decoding inputs, and the low-order bit hard-

30   decision values $h(w'_{1,k}), h(w'_{0,k}), h(v'_{1,k}), h(v'_{0,k})$,

and when the switch 41 outputs a priori probability ratio $L_a(u_k)$, the decoder 32 performs Turbo decoding on the soft-decision input values $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$, and the low-order bit hard-

5   decision values $h(w'_{1,k})$, $h(w'_{0,k})$, $h(v'_{1,k})$, $h(v'_{0,k})$, so as to calculate the log-likelihood ratio $L(u_k)$ of the low-order information bit. Since the switch 41 is initially connected to side I, an initial value 0 is output to the decoder 32 at a first

10   cycle of decoding. In the second and subsequent cycles of decoding, the switch 41 is connected to side II so that the a priori probability ratio $L_a(u_k)$ output from the deinterleaver 40 is output to the decoder 32.

15   More specifically, by performing calculations according to equations (4)-(7), the log-likelihood ratio $L(u_k)$ of the low-order information bit is determined.

         When the soft-decision input value

20   calculator 31 calculates the soft-decision input values $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$, provided as Turbo decoding inputs, and the low-order bit hard-decision values $h(w'_{1,k})$, $h(w'_{0,k})$, $h(v'_{1,k})$, $h(v'_{0,k})$, the received amplitude value calculator 33

25   calculates the received amplitude value $L_{ch}(u_k)$, based on the soft-decision input values $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$, provided as Turbo decoding inputs, and the low-order bit hard-decision values $h(w'_{1,k})$, $h(w'_{0,k})$, $h(v'_{1,k})$, $h(v'_{0,k})$. That is, by performing

30   calculations according to the following equations

(11)-(14), the received amplitude value $L_{ch}(u_k)$ is determined.

$$L_{ch}(u_k = 00) = \ln \frac{Pr(W'_k, V'_k \mid u_k = 00)}{Pr(W'_k, V'_k \mid u_k = 00)} \qquad (11)$$

$$L_{ch}(u_k = 01) = \ln \frac{Pr(W'_k, V'_k \mid u_k = 01)}{Pr(W'_k, V'_k \mid u_k = 00)} \qquad (12)$$

$$L_{ch}(u_k = 10) = \ln \frac{Pr(W'_k, V'_k \mid u_k = 10)}{Pr(W'_k, V'_k \mid u_k = 00)} \qquad (13)$$

$$L_{ch}(u_x = 11) = \ln \frac{Pr(W'_k, V'_k \mid u_k = 11)}{Pr(W'_k, V'_k \mid u_k = 00)} \qquad (14)$$

5

where $L_{ch}(u_k=00)=0$ because $u_k=00$ is designated as reference information bit.

The subtractor 34 subtracts the received amplitude value $L_{ch}(u_k)$ and a priori probability

10   ratio $L_a(u_k)$ from the log-likelihood ratio $L(u_k)$ of the low-order information bit, so as to output the extrinsic information probability ratio $L_e(u_k)$. That is, by performing calculations according to the following equations (15)-(18), the extrinsic

15   information probability ratio $L_e(u_k)$ is determined.

$L_e(u_k=00)=L(u_k=00)-L_{ch}(u_k=00)$

$-L_a(u_k=00)$ (15)

$L_e(u_k=01)=L(u_k=01)-L_{ch}(u_k=01)$

20    $-L_a(u_k=01)$ (16)

$L_e(u_k=10)=L(u_k=10)-L_{ch}(u_k=10)$

$$-L_a(u_k=10) \tag{17}$$

$$L_e(u_k=11)=L(u_k=11)-L_{ch}(u_k=11)$$

$$-L_a(u_k=11) \tag{18}$$

In the first cycle of decoding, an initial value $L_a(u_k=00)=L_a(u_k=01)=L_a(u_k=10)=L_a(u_k=11)=0$ is input.

When the subtractor 34 outputs the extrinsic information probability ratio $L_e(u_k)$, the interleaver 35 interleaves the extrinsic information probability ratio $L_e(u_k)$ for synchronization with the recursive systematic convolutional encoder 14 so as to output the interleaved extrinsic information probability $L_e(u_k)$ as a priori probability ratio $L_a(u_k)$.

When the soft-decision input value calculator 31 outputs the soft-decision input values $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$, provided as Turbo decoding inputs, and the low-order bit hard-decision values $h(w'_{1,k})$, $h(w'_{0,k})$, $h(v'_{1,k})$, $h(v'_{0,k})$, the interleaver 36 interleaves the soft-decision input values $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$, and the low-order bit hard-decision values $h(w'_{1,k})$, $h(w'_{0,k})$, $h(v'_{1,k})$, $h(v'_{0,k})$ for synchronization with the recursive systematic convolutional encoder 14.

When the received amplitude calculator 33 outputs the received amplitude $L_{ch}(u_k)$, the interleaver 37 interleaves the received amplitude $L_{ch}(u_k)$ for synchronization with the recursive systematic convolutional encoder 14.

When the soft-decision input value
calculator 31 outputs the soft-decision input
values $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$, provided as Turbo
decoding inputs, and the low-order bit hard-

5 decision values $h(w'_{1,k})$, $h(w'_{0,k})$, $h(v'_{1,k})$, $h(v'_{0,k})$,
and when the interleaver 35 outputs a priori
probability ratio $L_a(u_k)$, the decoder 38, like the
decoder 35, performs Turbo decoding on the soft-
decision input values $w'_{1,k}$, $w'_{0,k}$, $v'_{1,k}$, $v'_{0,k}$, and

10 the low-order bit hard-decision values $h(w'_{1,k})$,
$h(w'_{0,k})$, $h(v'_{1,k})$, $h(v'_{0,k})$, so as to calculate the
log-likelihood ratio $L(u_k)$ of the low-order
information bit.

More specifically, the log-likelihood

15 ratio $L(u_k)$ of the low-order information bit is
determined by performing calculations according to
equations (4)-(7).

The subtractor 39 subtracts the received
amplitude value $L_{ch}(u_k)$ and a priori probability

20 ratio $L_a(u_k)$ from the log-likelihood ratio $L(u_k)$ of
the low-order information bit so as to output an
extrinsic information probability ratio $L_e(u_k)$.
That is, like the subtractor 34, the subtractor 39
determines the extrinsic information probability

25 ratio $L_e(u_k)$ by performing calculations according
to equations (15)-(18).

When the subtractor 39 outputs the
extrinsic information probability ratio $L_e(u_k)$, the
deinterleaver 40 interleaves the extrinsic

30 information probability ratio $L_e(u_k)$ for

synchronization with the recursive systematic
convolutional encoder 11. The deinterleaver 40
feeds back the extrinsic information probability
ratio $L_e(u_k)$ as a priori probability ratio $L_a(u_k)$ to
5   the decoder 32.

By performing the above steps a
predetermined number of times, the log-likelihood
ratio calculating means 30 is capable of
calculating the log-likelihood ratio with improved
10   precision.

In addition to the log-likelihood ratio
$L(u_k)$ of the low-order information bit, the decoder
32 calculates the log-likelihood ratio $L(u_{0a,k})$ of
the parity bit generated by the recursive
15   systematic convolutional encoder 11 according to
the equation (8), in the last cycle of repeating
the steps.

Likewise, in addition to the log-
likelihood ratio $L(u_k)$ of the low-order information
20   bit, the decoder 38 calculates the log-likelihood
ratio $L(u_{0b,k})$ of the parity bit generated by the
recursive systematic convolutional encoder 14
according to the equation (9), in the last cycle of
repeating the steps.

25   When the decoder 32 calculates the log-
likelihood ratio $L(u_{0a,k})$, the determination unit 43
determines the parity bit of the recursive
systematic convolutional encoder 11 based on the
log-likelihood ratio $L(u_{0a,k})$ of the parity bit so
30   as to calculate the estimated value $u'_{0a,k}$ of the

transmitted parity bit.

More specifically, when the log-likelihood ratio $L(u_{0a,k}) > 0$, the assumed value $u'_{0a,k}$ of the parity bit is determined to be "1". When the

5   log-likelihood ratio $L(u_{0a,k}) \leq 0$, the assumed value $u'_{0a,k}$ of the parity bit is determined to be "0".

When the decoder 38 calculates the log-likelihood ratio $L(u_{0b,k})$, the determination unit 44 determines the parity bit of the recursive

10   systematic convolutional encoder 14 based on the log-likelihood ratio $L(u_{0b,k})$ of the parity bit so as to calculate the estimated value $u'_{0b,k}$ of the transmitted parity bit.

More specifically, when the log-

15   likelihood ratio $L(u_{0b,k}) > 0$, the assumed value $u'_{0b,k}$ of the parity bit is determined to be "1". When the log-likelihood ratio $L(u_{0b,k}) \leq 0$, the assumed value $u'_{0b,k}$ of the parity bit is determined to be "0".

When the log-likelihood ratio $L(u_k)$ of

20   the low-order information bit is output, the determination unit 44 calculates the estimated value u'_k of the low-order information bit u_k based on the log-likelihood ratio $L(u_k)$ of the low-order information bit.

25   That is, when a set of log-likelihood ratio $L(u_k=00)$, $L(u_k=01)$, $L(u_k=10)$, $L(u_k=11)$ is output, the information bit that corresponds to the maximum log-likelihood ratio is designated as the estimated value u'_k of the low-order information

30   bit u_k.

The determination unit 45 calculates the estimated value $u'_{coset,k}$ of the coset, based on the estimated value $u'_k (=u'_{2,k}, u'_{1,k})$ of the low-order information bit calculated by the determination

5 unit 44 and the estimated value $u'_{0a,k}, u'_{0b,k}$ of the parity bit calculated by the determination units 43 and 44.

For example, when the conversion 2 of Fig. 2(a) and Fig. 2(b) is denoted by the equation

10 (1), the calculation according to the equation (10) is performed so as to calculate $w''_{1,k}, w''_{0,k}, v''_{1,k}, v''_{0,k}$ and determine the estimated value $u'_{coset,k}$ of the coset by referring to the table of Fig. 4(d).

15 When the determination unit 45 calculates the estimated value $u'_{coset,k}$ of the coset, the determination unit 46 calculates the estimated value W''_k, V''_k of the transmitted signal point, based on the received signal point W'_k, V'_k and the

20 estimated value $u'_{coset,k}$ of the coset. In the estimated value $u'_{coset,k}$ of the coset, the signal point closest to the received signal point W'_k, V'_k is designated as the estimated value W''_k, V''_k of the transmitted signal point.

25 The determination unit 46 calculates the estimated values $u'_{z,k}, u'_{z-1,k}, …, u'_{3,k}$ of the high-order information bit based on the estimated value W''_k, V''_k of the transmitted signal point.

Thus, the second embodiment provides an

30 advantage in that the high-order information bit is

accurately estimated so that the probability of errors in decoding the high-order information is reduced.

5   Third embodiment

In the second embodiment, the log-likelihood ratio calculating means 30 calculates the log-likelihood ratio of the low-order information bit and the log-likelihood ratio of the

10   parity bit. Alternatively, Turbo decoding for calculating a branch metric of trellis using a linear sum of soft-decision input values, so as to calculate the log-likelihood ratio of the low-order information bit and the log-likelihood ratio of the

15   parity bit.

The third embodiment provides improvement in the calculation of soft-decision input values by the soft-decision input value calculator 31 and the method of branch metric

20   calculation.

In the related art, soft-decision input values are determined by calculating the square Euclidean distance 27 between the received signal point 26 and the transmitted signal point 25 (Fig.

25   8(b)). In the first and second embodiments, soft-decision input values are determined by calculating the Euclidean distances 28 and 29 between the received signal point 26 and the threshold value, as shown in Fig. 8(c).

30   The principle of Fig. 8(b) will now be

described using a mathematical expression. It is
assumed the transmitted signal point 25 is located
at (X, Y) in the X-Y coordinate system of the
signal state space for W, and the received signal
5   point 26 is located at (X', Y') in the X-Y
coordinate system of the signal state space for W'.

The soft-decision input value is
represented by the square Euclidean distance 27
between the transmitted signal point 25 and the
10   received signal point 26.

$$d^2(W', W) = (X' - X)^2 + (Y' - Y)^2 \qquad (19)$$

Assuming an additive white Gaussian channel, the
15   likelihood of the received signal point 26
occurring when the signal point 25 is transmitted
is given by the following equation using the
probability density function of two-dimensional
normal distribution.

20

$$Pr(W'|W) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left\{\frac{d^2(W', W)}{2\sigma^2}\right\} \qquad (20)$$

The equation for calculating the log-likelihood
ratio of the low-order information bit and the
25   equation for calculating the log-likelihood ratio
of the parity bit include a term for the likelihood

Pr(W'|W). Each of the equations (4)-(7) includes a term that is logarithm of the equation (20). In calculating the log-likelihood ratio of the low-order information bit and the log-likelihood ratio

5 of the parity bit according to the equations (4)-(7), the calculation can be simplified by simplifying the equation (20) as follows.

$$Pr(W'|W) \approx d'(W', W) \qquad (21)$$

where d'(W', W) is represented as follows.

$$d'(W', W) = h'(w'_{1,k}, w_{1,k}) \cdot d'x + h'(w'_{0,k}, w_{0,k}) \cdot d'y \qquad (22)$$

$$h'(w'_{1,k}, w_{1,k}) = \begin{cases} +1 : h(w'_{1,k}) = w_{1,k} \\ -1 : h(w'_{1,k}) \neq w_{1,k} \end{cases} \qquad (23)$$

10

where d'_x corresponds to the Euclidean distance 28 from the threshold value of Fig. 8(c), and d'_y corresponds to the Euclidean distance 29 from the

15 threshold value of Fig. 8(c).

By converting the square Euclidean distance 27 into the Euclidean distance 28, 29 from the threshold value of the signal constellation in the signal state space, the volume of calculation

20 can be reduced without producing deterioration in the soft-decision input values.

According to the third embodiment, there

is provided a method for reducing the volume of calculation needed in the decoders 32 and 38 for calculation of trellis branch metric, in addition to the method for reducing the volume of

5 calculation in the soft-decision input value calculator 31.

Assuming the use of Log-MAP decoding in the decoders 32 and 38, the branch metric γ of trellis $(S_{j,k},\ u_{2,k},\ u_{1,k},\ u_{0a,k})$ is calculated as

10 follows.

$$\gamma(S_{j,k}, u_{2,k}, u_{1,k}, u_{0a,k})$$
$$= Pr(W'_k, V'_k, S_{j,k}, u_{2,k}, u_{1,k}, u_{0a,k})$$
$$= \sum_{u_{0b,k}=0}^{1} Pr(W'_k | CS_{u_{0b,k}}) \cdot Pr(V'_k | CS_{u_{0b,k}}) \cdot Pr(u_{2,k}, u_{1,k})$$
$$= d'(W'_k, CS_{u_{0b,k}=0}) + d'(V'_k, CS_{u_{0b,k}=0})$$
$$+ d'(W'_k, CS_{u_{0b,k}=1}) + d'(V'_k, CS_{u_{0b,k}=1}) + L_a(u_{2,k}, u_{1,k})$$

$$(24)$$

where $CS_{u0b,k=0}$ indicates a coset for a case where

15 $u_{2,k},\ u_{1,k},\ u_{0a,k}$ are fixed and $u_{0b,k}=0$.

Similarly, $CS_{u0b,k=1}$ indicates a coset for a case where $u_{2,k},\ u_{1,k},\ u_{0a,k}$ are fixed and $u_{0b,k}=1$.

$Pr(W'_k,\ V'_k,\ S_{j,k},\ u_{2,k},\ u_{1,k},\ u_{0a,k})$ indicates joint probability for a case where the

20 low-order information bit is $u_{2,k},\ u_{1,k}$, the transmitted parity bit is $u_{0a,k}$, the trellis status

node is $S_{j,k}$ and the received signal points are W'_k, V'_k.

$Pr(W'_k|CS_{u0b,k})$ indicates the likelihood that the received signal point W'_k is received when
5   the transmitted signal with the coset $CS_{u0b,k}$ is transmitted.

$Pr(V'_k|CS_{u0b,k})$ indicates the likelihood that the received signal point V'_k is received when
—   the transmitted signal with the coset $CS_{u0b,k}$ is
10   transmitted.

$Pr(u_{2,k}, u_{1,k})$ indicates a priori probability of the low-order information bit $u_{2,k}$, $u_{1,k}$.

Using the equation (24), the branch
15   metric can be calculated as a linear sum of the Euclidean distance between signal points and a priori probability.

Thus, according to the third embodiment, calculation with respect to the communication
20   channel can be simplified. Further, calculation of the branch metric can be simplified. Accordingly, the circuit scale of the demodulating apparatus can be reduced.

25   Fourth embodiment

In the first through third embodiments, the use of the encoder of Figs. 2(a) and 2(b) is assumed. The first through third embodiments are assumed to be applied to an encoder where the
30   conversion 2 is installed.

In the absence of the conversion 2, i.e., when the low-order information bit and the parity bit are as indicated by the equation (25), for example, the branch metric γ is calculated as

5   follows.

$$
\begin{cases}
w_{1,k} = u_{2,k} \\
w_{0,k} = u_{0a,k} \\
v_{1,k} = u_{1,k} \\
v_{0,k} = u_{0b,k}
\end{cases}
\tag{25}
$$

$$
\begin{aligned}
\gamma(S_{j,k}, &u_{2,k}, u_{1,k}, u_{0a,k}) \\
&\approx h'(w'_{1,k}, u_{2,k}) \cdot d''(w_{1,k}) + h'(v'_{1,k}, u_{1,k}) \cdot d''(v'_{1,k}) \\
&\quad + h'(w'_{0,k}, u_{0a,k}) \cdot d''(w'_{0,k}) \\
&\quad + \frac{1}{2}\left\{ h'(1, u_{2,k}) \cdot La(u_{2,k}) + h'(1, u_{1,k}) \cdot La(u_{1,k}) \right\}
\end{aligned}
\tag{26}
$$

where $d''(w'_{1,k})$, $d''(v'_{1,k})$ each indicates the
10   Euclidean distance 28 from the threshold value of
Fig. 4(c) and $d''(w'_{0,k})$, $d''(v'_{0,k})$ each indicates
the Euclidean distance 29. $La(u_{2,k})$, $La(u_{1,k})$
indicate a priori probability of the low-order
information bit $u_{2,k}$, $u_{1,k}$, respectively.
15   The first through third embodiments are
assumed to be applied to the multi-carrier

demodulating method as shown in Fig. 2(c). However, the application is not limited to the method of Fig. 2(c).

While it is assumed in the above that
5   the information bit and the parity bit according to the Turbo encoding is divided into two tones at a given point of time, as shown in Fig. 2(c), alternative arrangements are also possible.

It is assumed that the first through
10   third embodiments are applied to the 16QAM demodulating method. The embodiments find applications in other methods of demodulation (for example, 256QAM) and still provide the same advantage.
15

INDUSTRIAL APPLICABILITY

As has been described, the demodulating method and apparatus according to the invention is suitably used in trellis coded demodulation using
20   Turbo codes as element codes, for accurate estimation of high-order information bits and reduction in error in decoding high-order information bits